Tunable dual-wavelength optical short-pulse generation by use of a fiber Bragg grating and a tunable optical filter in a self-seeding scheme

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A simple self-seeding scheme is developed to generate tunable dual-wavelength optical short pulses in a flexible manner and with an increased wavelength-tuning range. The wavelength selection and tuning are achieved by simultaneous use of a fiber Bragg grating and a tunable optical filter. The side-mode suppression ratio of the output pulses is better than 30 dB over a wavelength-tuning range of 33.8 nm. The system is compact and convenient for dual-wavelength tuning. © 2004 Optical Society of America

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1. Introduction

Wavelength-tunable optical short-pulse generation is of great interest in many optical fiber communication and sensor applications. A number of methods, such as mode locking of a laser source and gain switching of a Fabry–Perot (F–P) laser diode, have been used to produce optical short pulses.[1] Mode locking is one of the major techniques that produce optical short pulses at fixed repetition frequencies, but it requires a specially designed laser structure or an antireflection coating on the internal laser facet; precise system alignment is also critical to maintain the whole cavity stability.[2,3] Gain switching is a simple and economical method of short-pulse generation, and only commercially available F–P laser diodes are used; the system is more tolerant of misalignment, and the output pulses show better stability against fluctuation.[4,5] To produce wavelength-tunable optical short pulses from a gain-switched F–P laser diode, a simple self-seeding scheme can be adopted in which a wavelength-selective device is incorporated into the laser's external cavity and the selected wavelength element from the laser's output is reintroduced into the laser diode. Provided that the feedback arrives during the pulse's buildup time, single-wavelength optical short-pulse emission can be obtained. The commonly used wavelength-selective devices in self-seeding include diffraction gratings, fiber Bragg gratings (FBGs), and tunable optical F–P filters.[6–11] Diffractive gratings are bulk optical devices and have relatively large dimensions. FBGs have small dimensions and are compatible with optical fibers, but their wavelength-tuning range is limited, typically less than 20 nm in most of the reported systems. A large wavelength-tuning range can be achieved, however, by the use of a tunable optical F–P filter. However, tunable optical F–P filters are expensive, especially when dual-wavelength or multiwavelength operation needs to be supported.

For a tunable dual-wavelength or multiwavelength optical short-pulse system the important parameters that determine the usefulness of the system include the side-mode suppression ratio (SMSR) and the wavelength-tuning range. A SMSR of greater than 25 dB is usually required for most optical fiber communication applications.[12] However, in most self-seeding systems reported so far, the SMSR achieved is relatively low (<30 dB) or exhibits a limited wavelength-tuning range (typically less than 20 nm).[8]

In this paper we present a simple system for dual-wavelength optical short-pulse generation that uses a FBG and a tunable optical F–P filter simultaneously. The system is more economical than those that use two tunable optical F–P filters and, compared with the dual-FBG configuration, produces more-flexible wavelength tuning and a larger wavelength-tuning range. As the emitted dual-wavelength optical

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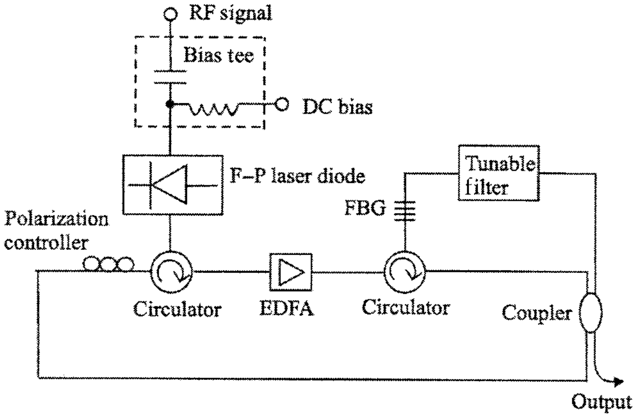

Fig. 1. Experimental arrangement of the dual-wavelength self-seeding scheme.

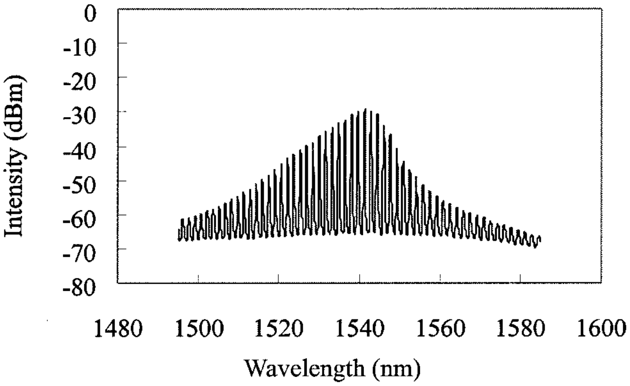

Fig. 2. Gain-switched F–P laser diode spectrum.

short pulses from the F–P laser diode experience further power amplification and spectral purification before being sent as the output, a relatively large SMSR can also be achieved. The system possesses a compact configuration and a relatively large wavelength-tuning range of 33.8 nm, with a SMSR larger than 30 dB.

2. Experiment

The experimental arrangement for the dual-wavelength self-seeding scheme is shown in Fig. 1. An approximately −19-dBm microwave-range electrical signal from a radio frequency (RF) signal generator (HP E4422B) is amplified by an electrical power amplifier (ZHL-42W, Mini-Circuits, Brooklyn, New York) with a gain of 30 dB and then split into two portions; ~10% of the signal power is used as the trigger to the oscilloscope, and the rest is used to drive the F–P laser diode into gain-switching operation via a bias-tee circuit. The laser diode is dc biased at ~8 mA, below its threshold current value of ~10 mA. The multimode output pulses from the gain-switched F–P laser diode are power intensified by an erbium-doped fiber amplifier (EDFA) and then wavelength selected by the use of a FBG and a tunable optical F–P filter through an optical circulator and a coupler (50:50) before being directed back into the gain-switched laser diode via another circulator. The Bragg wavelength of the FBG is ~1531 nm, and the wavelength-tuning range is ~14 nm, centered at the Bragg wavelength. The FWHM value of the spectral width of the FBG is ~0.3 nm. The tunable optical filter exhibits a bandwidth of 2.4 GHz and a free spectral range of 8860 GHz. The cavity lengths for the two wavelength elements reflected by the FBG and the tunable optical filter are different, which may lead to different arrival times at the gain-switched F–P laser diode. However, because of the dispersion effect, the optical pulses are broadened before they arrive at the laser diode, and, in addition, the arrival time window allowed for the self-seeding operation is a few tens of picoseconds[5]; thus the two wavelength elements are not required to reach the laser diode at exactly the same time. Provided that the repetition frequency of the pulses for each wavelength is a multiple of the round-trip propagation frequency for the corresponding feedback path, simultaneous dual-wavelength operation can be obtained. One can implement wavelength tuning by adjusting the FBG and the optical filter and slightly tuning the repetition frequency. The stimulated dual-wavelength pulses are further amplified in power and spectrally purified, again by use of the FBG and the tunable optical F–P filter, respectively, before being sent out from the optical coupler. A polarization controller is used in the optical loop to adjust the polarization states of injection light into the laser diode to optimize the SMSR of the output pulses. The spectra of the dual-wavelength optical pulse trains are observed by use of an optical spectrum analyzer with 0.1-nm resolution, and their wave forms are recorded on a high 25-GHz digital sampling oscilloscope.

3. Results and Discussion

The multimode output pulse spectrum from the gain-switched F–P laser diode is demonstrated in Fig. 2. The central wavelength of the laser diode is ~1540 nm, with mode spacing of ~1.6 nm. The linewidth of the laser mode is ~0.1 nm, limited by the resolution of the optical spectrum analyzer.

The dual-wavelength pulse spectra that we obtained are recorded in Fig. 3, where tunable dual-wavelength optical short-pulse operation is demonstrated. One achieves dual-wavelength tuning by applying strain to the FBG and varying the driving voltage on the tunable optical F–P filter. In Fig. 3(a) the peak wavelengths are situated at 1530.1 and 1531.6 nm, representing a small wavelength separation that is close to the laser mode spacing. By adjusting only the tunable filter, one can change the wavelength separation, as demonstrated in Fig. 3(b), where the two wavelengths are located at 1530.1 and at 1546.2 nm. In Fig. 3(c), the dual-wavelength separation is increased further, to ~30.8 nm, and the peak wavelengths appear at 1530.1 and 1560.9 nm. The linewidth of the emission wavelength is 0.2 nm for the FBG reflected pulses and 0.1 nm for the tun-

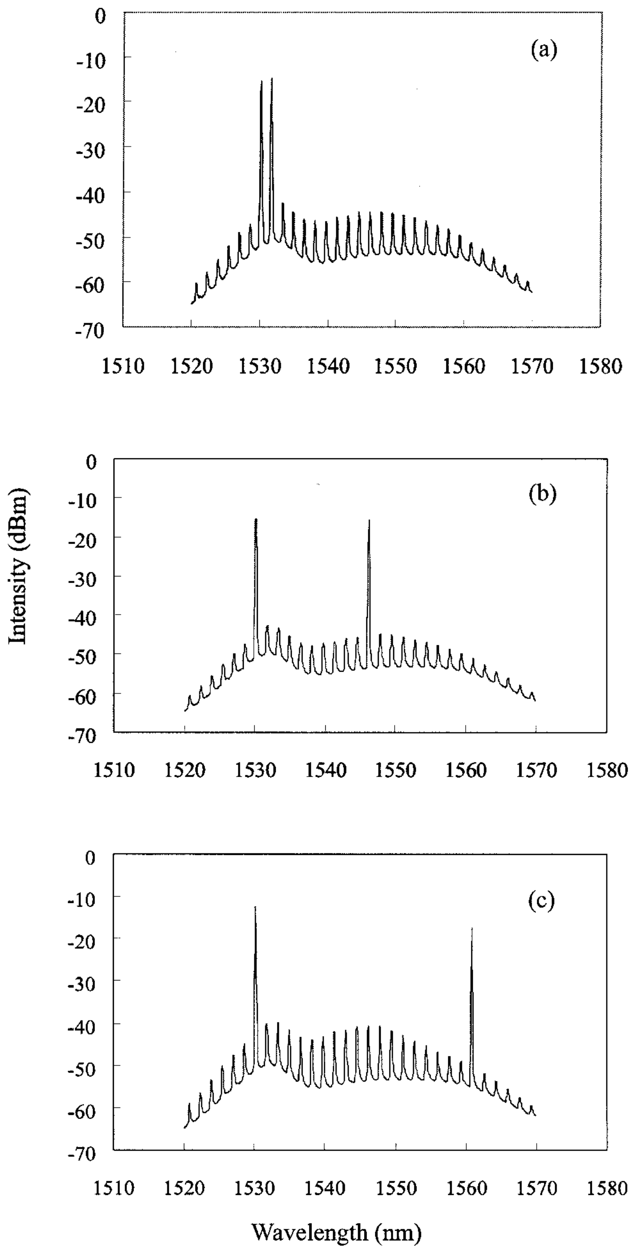

Fig. 3. Tunable dual-wavelength self-seeded output spectrum (a) at 1530.1 and 1531.6 nm, (b) at 1530.1 and 1546.2 nm, (c) at 1530.1 and 1560.9 nm.

able filter output, limited by the resolution of the optical spectrum analyzer.

One can also tune the dual wavelengths in a flexible manner by taking nearly the same wavelength separation as displayed in Fig. 4. In Fig. 4(a) the dual-wavelength peaks are situated at 1528.5 and 1534.9 nm. By adjusting the FBG and the tunable F–P filter, one can shift the two wavelengths to 1531.8 and 1538.2 nm in Fig. 4(b) and further to 1534.9 and 1541.3 nm in Fig. 4(c), respectively. Although the dual wavelengths are located at different peaks, nearly the same wavelength spacing of ~6.4 nm can be maintained.

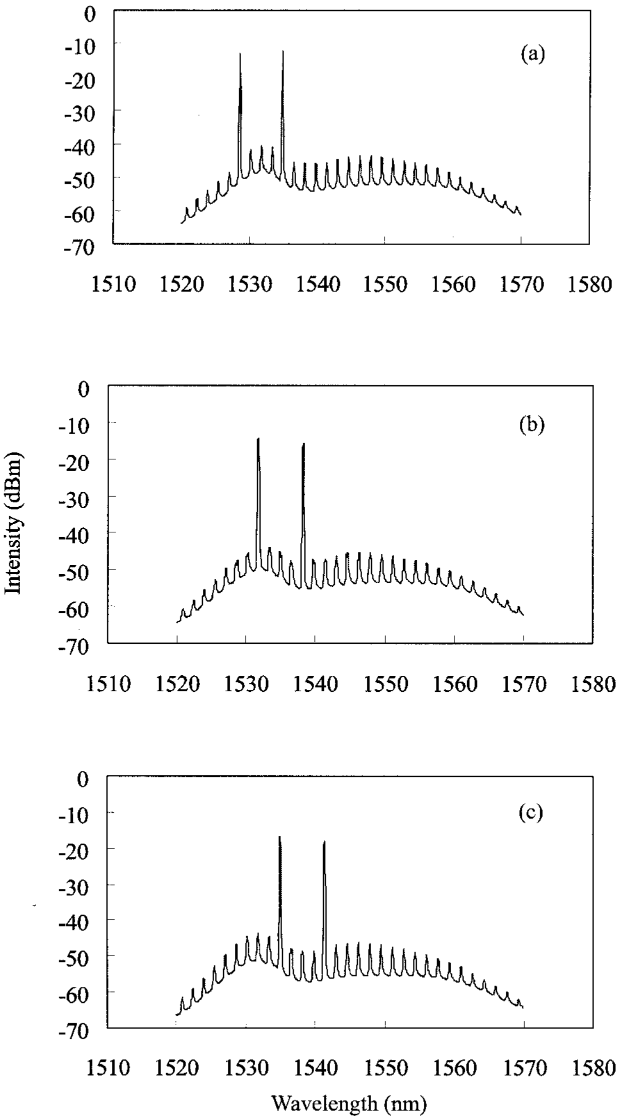

Fig. 4. Tunable dual-wavelength self-seeded output spectrum with fixed wavelength separation (a) at 1528.5 and 1534.9 nm, (b) at 1531.8 and 1538.2 nm, (c) at 1534.9 and 1541.3 nm.

The optical pulse trains that correspond to the two wavelengths displayed in Fig. 3(b) are shown in Fig. 5. The FWHM values of the pulse widths are ~300 and ~350 ps and correspond to the FBG and the tunable filter selected pulses, respectively. The relatively large pulse width is due to the frequency chirp caused by inherent reduction in carrier density during pulse emission. As the two pulse trains that correspond to the two wavelengths overlap in the output, we employed a tunable optical filter to select one of the pulse trains.

The values of SMSRs obtained at different wavelengths are demonstrated in Fig. 6. It can be seen from this figure that, for a SMSR larger than 30 dB, a wavelength-tuning range of 33.8 nm can be obtained that corresponds to wavelengths of 1528.6–1562.4 nm. Within this wavelength range the values of the SMSR are 30–35 dB, representing a

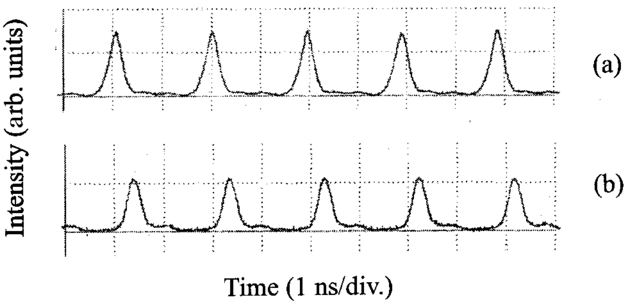

Fig. 5. Output pulse trains (a) at wavelength 1530.1 nm and (b) at wavelength 1548.1 nm.

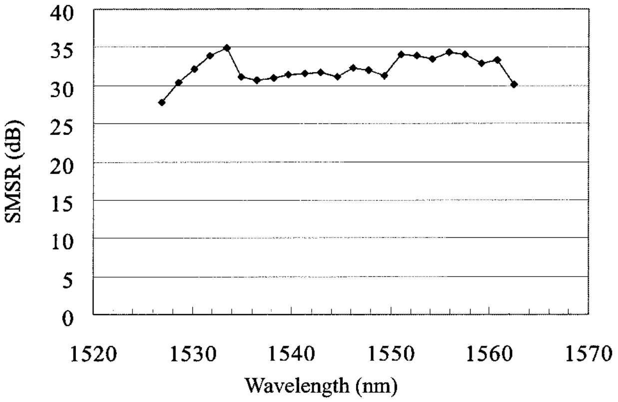

Fig. 6. Measured SMSRs of the output pulses at several wavelengths.

rather smooth variation. The difference in SMSR obtained at the output of the self-seeded laser diode and that at the output of the system is small, typically less than 3 dB. The maximum wavelength-tuning range is limited by the spectrum of the F–P laser diode and the gain curve of the EDFA used in the system setup. The value of the SMSR depends on the gain width of the laser diodes, the gain of the EDFA employed, and the polarization states of the pulse trains.

4. Conclusions

A simple self-seeding system has been demonstrated to produce tunable dual-wavelength optical short-pulse trains. The wavelength-tuning range achieved that corresponds to a SMSR greater than 30 dB is 33.8 nm. The system is compact and convenient for dual-wavelength tuning.

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